Chapter 1

Perspectives on Climate Effects on Agriculture: The International Efforts of AgMIP in Sub-Saharan Africa

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Introduction

Agriculture in Sub-Saharan Africa (SSA) is experiencing climate change-related effects that call for integrated regional assessments, yet capacity for these assessments has been low. The Agricultural Model Intercomparison and Improvement Project (AgMIP) is advancing research on integrated regional assessments of climate change that include climate, crop, and economic modeling and analysis. Through AgMIP, regional integrated assessments are increasingly gaining momentum in SSA, and multi-institutional regional research teams (RRTs) centered in East, West, and

Southern Africa are generating new information on climate change impacts and adaptation in selected agricultural systems. The research in Africa is organized into four RRTs and a coordination team. Each of the RRTs in SSA is composed of scientists from the Consultative Group of International Agricultural Research (CGIAR) institutions, National Agriculture Research institutes (NARs), and universities consisting of experts in crop and economic modeling, climate, and information technology. Stakeholder involvement to inform specific agricultural systems to be evaluated, key outputs, and the representative agricultural pathways (RAPs), is undertaken at two levels: regional and national, in order to contribute to decision-making at these levels. Capacity building for integrated assessment (IA) is a key component that is undertaken continuously through interaction with experts in regional and SSA-wide workshops, and through joint creation of tools. Many students and research affiliates have been identified and entrained as part of capacity building in IA. Bi-monthly updates on scholarly publications in climate change in Africa also serve as a vehicle for knowledge-sharing. With 60 scientists already trained and actively engaged in IA and over 80 getting monthly briefs on the latest information on climate change, a climate-informed community of experts is gradually taking shape in SSA. (See Part 2, Appendices 3–5 in this volume for AgMIP Regional Workshop reports.)

Integrated Assessment in SSA

Agriculture in SSA is largely characterized by low inputs and is experiencing climate change-related effects that call for regional integrated assessments. In addition to overall increases in temperature and CO_2 concentrations, regional effects are driven by three key factors, namely tropical convection, monsoons, and the El Niño Southern Oscillation (ENSO). In West Africa, for example, the Sahelian rainfall has strong correlations with the latitudinal position of the Intertropical Convergence Zone (ITCZ; Hastenrath and Polzin, 2011), and there is a unique phenomenon called the monsoon jump (abrupt latitudinal shift of maximum precipitation from the Guinean coast into the Sahel region (Samson and Cook, 2007)). Climate change is likely to affect these drivers in the three major regions in complex and interactive ways.

These three regions, which also differ in terms of their Koppen–Geiger climate classification (Peel *et al.*, 2007), form the key study areas of the AgMIP IA in SSA. Existing information based on modeling of future climate seems to agree on drier western and southern Africa regions and a wetter eastern Africa, although there are intraregional variations (see also Part 2, Chapters 2–5 in this volume). The objective of this chapter is to provide the state of knowledge of modeled climate changes and their effects on crop productivity and household economies, and to present the efforts of AgMIP in furthering IA in SSA.

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Climate change in SSA

There is agreement among different general circulation models (GCMs) and associated research that Africa should brace itself for a warmer future world (Waha *et al.*, 2013; see also Part 2, Chapters 2–5 in this volume). Shifts in current zones for agriculture due to climate change have also been suggested, including shifts in the distribution of Köppen–Geiger climate classifications (Hachigonta *et al.*, 2013; Läderach *et al.*, 2013; Mahlstein *et al.*, 2013). The pace of the shifts is related to increasing global temperature driven by greenhouse-gas concentrations in the atmosphere. It is expected that temperature changes of up to 2°C would result in climate shifts in 5% of the land and the agricultural impacts of the shifts will vary depending on the amount of land used for agriculture compared to other purposes such as ecosystem (e.g., number of endemic species) or population support (Mahlstein *et al.*, 2013). Some reports, such as that of Zhang and Cai (2013), indicate that climate change may generally favor agriculture in SSA. Others warn that the resulting food-production gains in SSA are likely only in the short run (2030), with losses in the long run (2090; Liu *et al.*, 2013). Most reports however suggest differentiated effects of climate change on agriculture in the regions of SSA (see Hachigonta *et al.*, 2013; also Table 1). For example, by 2050, maize yield may increase or decrease by 25% in Malawi and Zimbabwe, depending on the location, and cotton production in Malawi could double (Hachigonta *et al.*, 2013).

The climate change results suggest the need for adaptations if productivity in some of the current SSA production areas is to be sustained, and several researchers have made recommendations. The most comprehensive generalized list of possible adaptation practices in SSA is perhaps by Naab *et al.* (2013) in a previous volume of this series (i.e., Hillel and Rosenzweig, 2013). Some suggested adaptation practices by Naab *et al.* include choice of disease-/drought-resistant crops and their arrangement in sequential cropping systems (Bello *et al.*, 2013; Okonya *et al.*, 2013; Waha *et al.*, 2013), diversity in cropping activities (Muller *et al.*, 2013), improved farm management practices such as use of high levels of nutrients, increased area under irrigation, and high-yielding cultivars (Calzadilla *et al.*, 2013; Delgado *et al.*, 2013; Folberth *et al.*, 2013), and livelihood diversification (Bryan *et al.*, 2013). Since adaptive capacity is dependent on individual resource endowment (Turner and Rao, 2013; Yegbemey *et al.*, 2013), rights of land tenure (Yegbemey *et al.*, 2013), and technological changes (Dietrich *et al.*, 2013), low-income farmers are more vulnerable to the impacts of climate change (Skjeflo, 2013). Thus the complexity and heterogeneity in socio-economic and climatic conditions require adaptation options that consider multiple factors, impacts, vulnerabilities, and potentials. Participation by policymakers and the community is important in the development of adaptation strategies (Bidwel *et al.*, 2013; Vermeulen *et al.*, 2013) and is central to the IA initiatives of AgMIP.

Table 1. Recently published changes in temperature and rainfall predicted for future of SSA.

Temperature	Rainfall	Yield	Model	Focus region	Time-slice	Source
1.5–2	Little change except increasing in extreme northern region	Decreases and increases	CSIRO, MIROC	Zimbabwe	2000–2050	Mugabe *et al.* (2013)
1–1.5	No change	More maize in northern and central regions, less in southern region	CSIRO	Malawi	2000–2050	Saka *et al.* (2013)
1–2	+50 to 400 mm	Increase maize in northern and central regions, decrease in southern region	MIROC5	Malawi	2000–2050	Saka *et al.* (2013)
—	—	Increase	HadCM3, CGCM2, CSIRO2 and PCM	Africa	2030	Liu *et al.* (2013)
—	—	Losses	HadCM3, CGCM2, CSIRO2 and PCM	Africa	2090	Liu *et al.* (2013)
0.5–2.0	+100 to 300 mm	Increase	MIROC5	Kenya	2000–2050	Odera *et al.* (2013)
1–1.5	No change	Increase	CSIRO	Kenya	2000–2050	Odera *et al.* (2013)
1·4–4·1	+10 to −40%			Ethiopia	2080	Kassie *et al.* (2014)
1–3	>80% of the models variable	—	15 GCMs	Southern Africa	2030–2060	Tadross *et al.* (2011)

AgMIP in SSA

A call for IA in Africa was made by Desanker and Justice (2001) in a special issue of *Climate Research* dedicated to climate change in Africa. However, the challenge for IA for agriculture in SSA is partly related to data-access issues (Cooper *et al.*, 2013) (hence the common use of coarse secondary data; see, e.g., Fischer *et al.*, 2005), and partly to low local technical capacity. Also, while IA requires transdisciplinary approaches, most climate change studies have remained linear, with information flowing from one discipline to another with little cross-disciplinary interaction. AgMIP tries to fill these existing gaps by integrating climate change, agricultural productivity, and socio-economic aspects through coordinated modeling, executed in a looped approach. The key questions that AgMIP is addressing relate to the sensitivity of current agricultural production systems to climate change, the impact of climate change on future agricultural production systems, and the benefits of climate change adaptations. The range of models used in these integrated regional assessments are reported in a comparative review by Dumollard *et al.* (2012), and some of the economic models include crop and climate (as emulator) modules. In AgMIP, the Tradeoff Analysis Model for Multi-dimensional Impact Assessment (TOA-MD) economic model (Antle *et al.*, 2014) is used, taking as input the output of dynamic crop growth models (mainly DSSAT (Decision Support System for Agrotechnology Transfer) and APSIM (Agricultural Production Systems Simulator), and in some cases AQUACROP and SarraH) and of livestock models such as LivSim (Livestock Simulation Model) and APSFarm (APSIM's Whole-Farm Systems Model). Figure 1 shows the conceptual flow of the IA approach used in AgMIP. The assessments are achieved through coordinated efforts among a multi-disciplinary team composed of climate, crop, and socio-economic scientists (Rosenzweig *et al.*, 2013) who work closely with innovative experts in agricultural-systems information technology.

AgMIP's work on IA in SSA responds to the recommendations of Cooper *et al.* (2013) on the need to (1) improve access to information, (2) build research capacity, and (3) enhance the impact of the research undertaken as the foundation for tackling the climate change challenges in agriculture. The RRTs are the primary groups through which AgMIP is conducting the assessments. The RRTs are multi-country, multi-institutional, multi-disciplinary groups of leading and upcoming scientists in climate, crop, and economic modeling and information technology (IT) in SSA (Table 2). The four RRTs in SSA include impacts of climate variability and change on agricultural systems in East Africa (AgMIP EA), climate change impacts on agricultural systems in West Africa (CIWARA), the Southern Africa Agricultural Model Intercomparison and Improvement Project (SAAMIIP), and Crop–Livestock Intensification in the Face of Climate Change Project (CLIP;

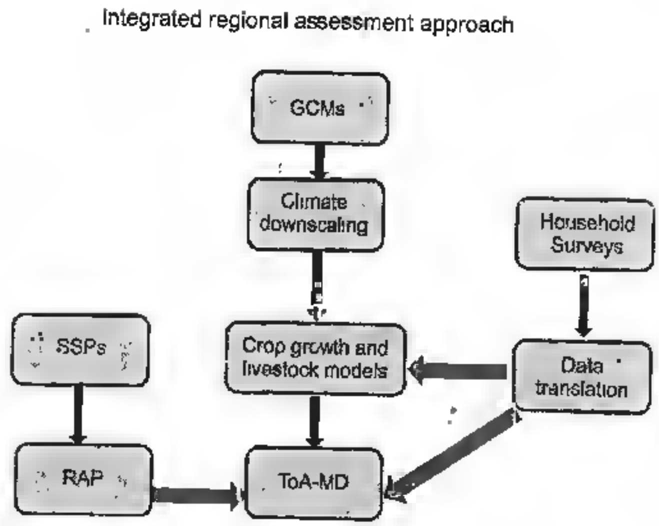

Fig. 1. Integrated regional assessment approach used in AgMIP. GCMs = global climate models, SSPs = shared socio-economic pathways, RAP = representative agricultural pathways.

see Rosenzweig *et al.*, 2013). The RRTs cover the AgMIP regions, countries, and research locations shown in Fig. 2. Each team includes an AgMIP resource person (ARP) who liaises between AgMIP leadership and investigators involved in RRT activities. The multi-disciplinary team of researchers work together not only to understand key disciplinary assumptions (Rosenzweig, 2012), but to define and test assumptions used in the AgMIP integrated modeling approach. A fifth team on knowledge enhancement for climate change referred to as the SSA coordination team provides support for coordinating capacity building and communication amongst the RRTs. The project principal investigators (PIs) and ARPs have formed an SSA leaders committee with scheduled monthly meetings in which management and scientific progress within teams are discussed.

AgMIP has followed a phased approach in order to realize twin goals of capacity building and IA. The first phase was the Fast Track (September 2012 to July 2013), which aimed at getting the basics right and preparing teams to realize the set modeling objectives. This initial phase focused on a few sites where all the modeling activities were implemented at RRT level before teams spread out to conduct research at multiple sites simultaneously (the Homestretch; August 2013–January 2014). In both phases, five general GCMs were used in the three regions, although in some cases up to 20 GCMs have been used, e.g., in East Africa. Baseline (current climate (1980–2010)), mid-century (2040–2070), and end of century (2070–2100) are the three time-slices used. The specific research methods, GCMs, and modeling projections are contained in Part 2, Chapters 2–5 in this volume.

Table 2. Affiliations of AgMIP scientists in SSA.

Institutioo(s)	Country	Type of institution	Number of scientists
Crop Research Institute in Kumasi	Ghana	NARS	4
University of Ghana	Ghana	University	2
University for Development Studies	Ghana	University	1
SARI	Ghana	NARS	1
Agence Nationale de l'Aviation Civile et de la Meteorologie	Senegal	NARS	1
Agrhymet	Niger	Regional	3
Agricultural Research Corporation	Sudan	NARS	1
Botswana College of Agriculture	Botswana	University	2
French Agricultural Research Centre for International Development (CIRAD)	France	International center	1
CIAT	Kenya	CG center	2
Department of Climate Change and Meteorological Services	Malawi	NARS	1
University of Malawi	Malawi	University	2
Directioo Nationale de la Météorologie du Mali	Mali	NARS	1
Mekelle University	Ethiopia	University	
Ethiopia Met Agency,	Ethiopia	NARS	
Ethiopian Institute of Agricultural Research	Ethiopia	NARS	4
Human Sciences Research Council (HSRC)	South Africa	NARS	2
ICRISAT	Kenya, Niger, Zimbabwe	CG center	7
Institut de l'Environnement et de Recherches Agricoles	Burkina Faso	NARS	1
Institute of Rural Development Planning	Tanzania	NARS	1
IPAR	Senegal		1
Kenya Meteorological Department	Kenya	NARS	
University of Nairobi	Kenya	University	
Kenya Agricultural Research Institute	Kenya	NARS	
Uganda Meteorological Department	Uganda	NARS	4
Makerere University	Uganda	University	5
Meteorological Services of Swaziland	Swaziland	NARS	1
National University of Lesotho	Lesotho	University	1
Polytechnic of Namibia	Namibia	University	2
Sokoine University of Agriculture	Tanzania	University	2
Tanzania Meterological Agency	Tanzania	NARS	2
Universidad Eduardo Mondlane	Mozambique	University	1
University of Cape Town	South Africa	University	3
University of Free State	South Africa	University	3
Agricultural Research Council (ARC)	South Africa	NARS	2
South African Sugarcane Research Institute (SASRI)	South Africa	NARS	2

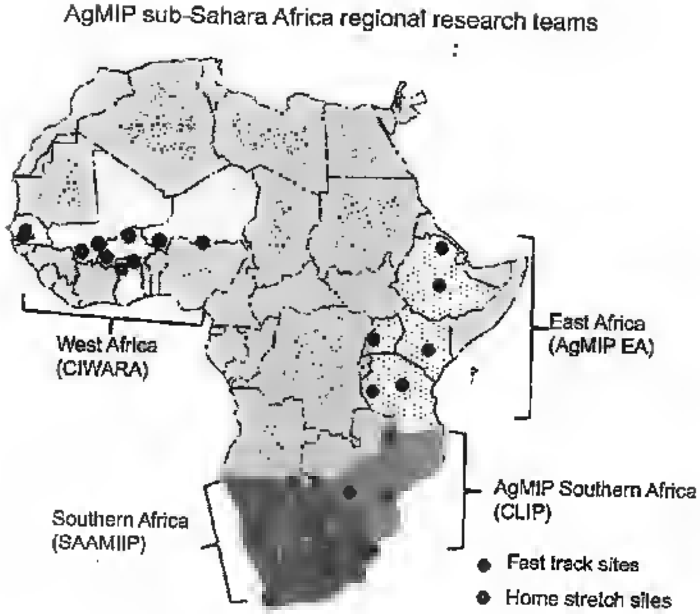

Fig. 2. AgMIP regions, countries, and integrated assessment locations for the AgMIP SSA RRTs.

Identifying and Integrating Stakeholder Concerns

Effective adaptation to climate change and management of risks requires networking between researchers and decision-makers (Bidwel *et al.*, 2013). In SSA, high stakeholder expectations for credible and acceptable IA results are being addressed through an inclusive process where stakeholder concerns are integrated in the assessments. The value of such results was presented by Vermeulen *et al.* (2013), who noted that policymakers in planning for agricultural adaptation would be ready to accept and use "tangible and practical" model outputs on future scenarios of agriculture due to climate change.

Levels of engagement

Stakeholders are engaged at RRT and SSA-wide levels. At the SSA level, stakeholders, mainly technocrats in the agriculture and environment ministries, provide input to the preliminary model simulations of the different teams, and discuss priority food security issues and needs of policymakers that AgMIP can address, including the best ways for AgMIP to disseminate research outputs in the countries. The stakeholders also provide an inventory of key projects in each region/country on climate change so that AgMIP can collaborate and create synergies. Interactions

with stakeholders at the SSA level have provided AgMIP scientists with an opportunity to encourage the inclusion of climate change adaptation plans in government strategy, where these are yet to be included. The engagement forums are also opportunities for countries to learn from those who are ahead in development of the adaptation plans and where scientists are encouraged to move from pilot studies to implementation, and to increase opportunities for integrating science (AgMIP research) and development (appropriate non-governmental organization (NGO) activities).

Key stakeholder concerns

The fusion of farmer concerns, farming systems research, and policymaking brings key challenges for linking science and practice. Making the scientific process useful to decision-making is an outcome that AgMIP researchers and stakeholders strive to achieve in order to create impact through relevant research, better interpretation, visualization, and presentation of results and their communication beyond project partners. This necessitates the AgMIP research teams to engage in discussion with multiple stakeholders to understand context and priorities, addressing questions such as: What are the adaptations currently under consideration? Where do they fall short? What time-scales are most important to the process? What level of detail should key messages contain to be of most use to policymakers? What can stakeholders do to help advance the collaborative AgMIP research methodology? How is climate change information most effectively communicated? How might improved communications be undertaken? What factors limit information-sharing and/or public perception of opportunity through adaptation? What regulatory frameworks are needed to encourage uptake of climate change adaptation strategies (i.e., how can the outcomes of AgMIP's IA activities be implemented)? While the primary concern of stakeholders is the identification and advancement of practices that further versatile and profitable crop management technologies, stakeholder-need discussions tend to fall into science, time-scales, and communication frameworks.

Science

Climate change work should:

(1) Expand in geographical coverage to cover the representative range of soil, climate, and socio-economic situations in SSA as well as temporal variations in the near- and long-term.
(2) Consider drastic/extreme events that may be part of the future climate despite no change in mean rainfall and/or temperature.

(3) Address the question of "what will be the critical point at which the high-potential areas (projected at present not to be affected badly by climate change) become vulnerable?"
(4) Consider changes in and effects of pest/diseases on crop productivity, and address reactions to climate change of crops with different photosynthetic pathways (C3 or C4 plants).
(5) Take into account the broader environmental degradation, including how it is affected by climate change and the feedbacks between the two, e.g., due to extreme events.
(6) Apportion the changes in future productivity to climate change and to degradation of the production base.

Additional work is needed to find out the profitability of the range of options beyond what is tested in AgMIP presently and how much farmers are willing to change to adopt them. This requires participatory action research that involves work with farmers to identify the different constraints and opportunities they would want to seize. Indeed, AgMIP economic analyses show a range of outcomes (losers and gainers) from the various options tested. The analyses could seemingly go an extra step to present alternatives to communities impacted, while also quantifying the benefits of adaptation compared to not taking action. African cropping systems typically involve intercropping of two or more crops—so are more complex than dynamic crop growth model systems at present, which are generally set up to simulate only mono-cropping systems. Researchers need to be able to discuss the extent to which over-simplification impacts adaptation strategies, and what is being done to improve model system simulations to consider even "simple" intercropping systems more appropriately. Scaling of IA results from individual farms to the landscape, regional, and national levels are needed in order to inform policy appropriately.

Time-scales

Although modeling initiatives such as AgMIP have a long-term futuristic focus such as mid-century or late-century time-horizons and their findings directly overlap with needs of development agencies, water resource infrastructure managers, or seed breeders, many farmers want a solution for their immediate/short-term problems. AgMIP is engaging with stakeholders to resolve conflicts in researcher and farmer time-scales considering that both short-term and long-term plans are needed to address climate change. Most countries operate on 5–10-year plans and modelling results of a long-term future (e.g., 50-year time-frames) must be formulated for relevance to the short decision time-frames of farmers and governments. This is important considering that farmers apply heavy discounts to the future (i.e., they invest in short-term benefits).

Communications

Climate change modeling results are associated with high degrees of uncertainty. How this uncertainty in results is communicated to the stakeholders matters. Presenting climate change information to include both positive and negative outlooks is important as opposed to the use of scare tactics about future climate. The messages must be simple and tailored to the target, whether it be farmers or policymakers, most of whom do not speak the language of graphs. The messages can highlight the role of stakeholders and policy in addressing the negative activities contributing to climate change (e.g., activities even external to the agricultural sector). Climate-smart agriculture is becoming more relevant today and, coupled with working agromet services and the evolution of ICT, including bulk and voice-based messaging services, and site-specific production advice in real time is possible.

Refining the stakeholder engagement process

Involvement of stakeholders at all levels is helpful in order to develop comprehensive adaptation packages. In many projects, stakeholders become an add-on to a project designed and implemented without them (see Fig. 3). Usually the stakeholders are invited for a workshop or a project meeting at which they need to advise on communication of results that they are not party to. Project leaders need to identify and sustain the needed engagements at the various project stages. AgMIP RRTs are incorporating feedback from stakeholder into analyses, reports, and publications, and continuously adjusting project plans to accommodate the concerns. Project

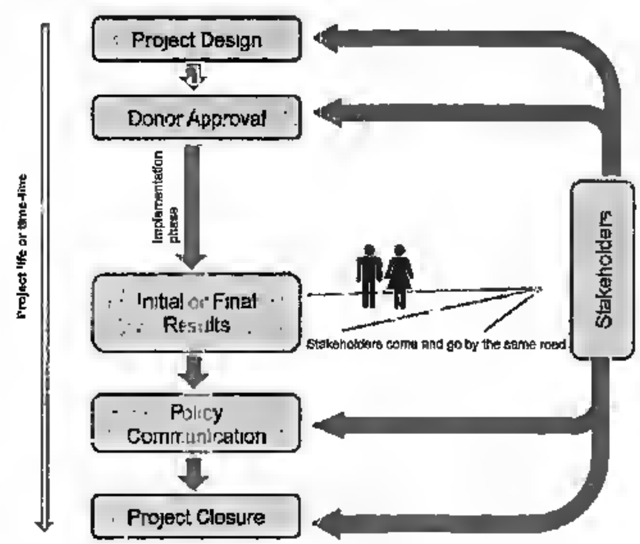

Fig. 3. Stakeholder engagement in project time-line.

self-evaluation is important to assess the evolving needs such as improvements on outreach to farmers and policymakers, and identifying linkages with other related ongoing or emerging initiatives for synergies in addressing the problems in question.

Interactions and engagements in RAP development

The RAP development process is interactive, requiring inputs from stakeholders (Antle, 2011). The definition and considerations of RAPs (including economic and social development storylines, trends in agricultural technology, prices, and costs) are available at www.agmip.org and tradeoffs.oregonstate.edu (see also Rosenzweig *et al.*, 2013). Several RAPs were defined from stakeholder consultations and from the participatory impact pathway analysis. AgMIP Teams are bringing together a wide range of stakeholders in this process including national policymakers, subregional level (such as the Economic Community of West African States (ECOWAS), etc.), and local actors (farmer groups, agricultural NGOs, etc.), with whom extensive discussions are facilitated. Two RAPs were developed for Nioro (Senegal), West Africa, based on four CCAFS scenarios (plausible alternate narratives of the future in terms of socio-economic and political change and the effects of these futures on food security, environments, and livelihoods; see http://ccafs.cgiar.org/). Similarly, 15 stakeholders participated in the development of RAPs for Kenya, building on earlier work through CCAFS. AgMIP is quickly expanding knowledge on RAPs and building the capacity of scientists across SSA and other regions where there is now knowledge of development of the RAPs. Both breadth and depth is needed; AgMIP also endeavors to engage selected stakeholders repeatedly, effectively engaging them in helping to design the looped process of a decision-informed research.

Capacity Building for Climate Change Modeling, Model Intercomparisons, and Improvements

Scientists in SSA require knowledge of the scaling of modeling results. This includes downscaling climate data, economic modeling, and its application in climate impact assessments, and accounting for uncertainties, among others. AgMIP scientists conducting IA are "standing on the shoulders of giants", by continuously interacting and learning from the parents and grandparents of modeling, mainly the model developers. As such, a new generation of modelers with high technical capacity is coming up in SSA. AgMIP is the first major effort to simultaneously build capacity on climate, crop, and economic modeling in SSA. The intensive interactions between model developers and the scientific community in SSA are ensuring in-depth understanding of the working of models and enhanced trouble-shooting capabilities. The capacity building for modeling is further strengthened by training in appropriate presentation

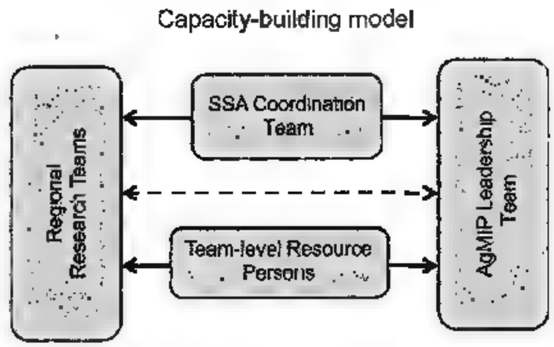

Fig. 4. Identification of capacity-building needs within SSA AgMIP regional teams.

and interpretation of modeling results, and in the communication of the information in relevant forms.

Identification of training needs in AgMIP follows the approach in Fig. 4. Each RRT identifies key areas of capacity-building needed in conjunction with the coordination team. Also, the ARPs within each RRT help to identify needs through routine interactions with project team members. Team-specific training needs, such as individual model parameterization and calibration, are addressed at team level while cross-cutting needs are addressed in SSA-wide forums. The AgMIP approach to capacity-building in modeling is incremental; needs are addressed as they are encountered and it embraces a learning-by-doing approach. Training workshops are preceded by pre-workshop activities, in which teams fulfill a checklist of tasks to prepare so as to maximize learning. See Part 2, Appendices 1 and 2 in this volume for multiple crop model and economic training workshop reports.

Training at RRT level

Multi-pronged training approaches have been adopted in AgMIP within all the RRTs, and several scientists have been trained at least in one key area beyond their prior experience. In addition, cross-disciplinary capacity building has ensured understanding within the integrated research teams. For West Africa, nine scientists have been trained in advanced model calibration at a Multi-Crop Model Training Workshop at ICRISAT, India (see also Part 2, Chapter 13 and Appendix 1 in this volume). Similarly, AgMIP scientists in East Africa trained in the use of crop simulation models (APSIM and DSSAT) and the economic model (TOA-MD; see Part 2, Appendix 2 in this volume), while in Southern Africa, a series of APSIM and LivSim trainings were organized. The trained AgMIP scientists are now generating downscaled climate scenarios, calibrating and validating various crop simulation models in the

target locations, and utilizing the TOA-MD model to project socio-economic outcomes of climate change. Additionally, research assistants and research affiliates are in regular contact with AgMIP scientists for consultation on issues and difficulties they encounter, as and when the need arises. Another capacity-building approach is extended training through MSc programs and full-time hosting of young modelers as visiting research fellows, e.g., the University of Ghana hosting research affiliates. Leading modelers at universities and the Consultative Group of International Agricultural Research (CGIAR) centers also contribute to capacity-building through supervision of university students and staff in other projects.

Training of trainers

Sustainability of capacity-building efforts in Africa is needed, and there have often been failures of previous efforts. Most of the previous efforts have been one-off training workshops with only a few instances of follow-up being sustained (Bationo *et al.*, 2012). In many of these efforts, the trainees were not affiliated with a project in which lessons learnt could be implemented. AgMIP adopted a different approach in which focus is on capacity-building within the project, with scientists immediately implementing the new knowledge. To ensure sustainability, and to develop capacity-building within Africa for Africa, AgMIP has adopted a "training of trainers" approach where promising young crop and economic modelers are involved in the training of their own colleagues. Trainers are distributed across the different SSA regions and RRTs. The trainers have conducted APSIM training in Southern Africa, and DSSAT and APSIM training in West Africa, both in workshops and in specialized one-on-one sessions (see also Part 2, Chapter 13 and Appendix 1 in this volume).

Communication for Impact

SSA level

Information-sharing among scientists and projects in SSA is key to unlocking the potential for IA. As such, the AgMIP SSA coordination team ensures inter-team communication and information-sharing through coordination of monthly virtual meetings of the RRT PIs and ARPs. Also, interteam updates that include key achievements and progress of the individual teams and some synthesis of the most up-to-date knowledge on specific topics (reviewed on a monthly basis) relevant to AgMIP scientists, are shared. The centralized monthly literature review supports teams within SSA with current, topical, and relevant literature for referencing. Through AgMIP's SSA coordination team, a network of climate, crop, and economic modelers has also been established, including AgMIP and non-AgMIP scientists. The monthly

updates are shared with this extended network of modelers with the aim of creating a climate change-aware community of experts in SSA. The monthly briefs are also shared on a blog posted on the AgMIP website (agmip.org; see example below).

AgMIP products are needed for a wide range of audiences at different literacy levels. This is important because access to agricultural information is one of the factors that highly influences farmers' practices (Yegbemey *et al.*, 2013). To realize impact, not only is the right message required in the right form but the right communication channels must be used. In line with this, policy messages or briefs are developed with the help of policymakers. Channels for communicating policy messages include local radio, and AgMIP, through its regional coordination team, is building a network of these channels. The high-level technocrats who participate in AgMIP SSA-wide activities are helping to communicate AgMIP results further.

RRT level

RRTs operate at a regional level and each RRT has developed its own internal and external communication plans. Internal communication is generally through the project PIs. For the two teams in Southern Africa, joint team meetings are held regularly and an oversight committee, composed of members of both teams, ensures complementarity in modeling activities. AgMIP RRTs have designed strategies to ensure open access to information, in which each RRT has websites where its results are communicated and shared, in addition to publications, presentations, and reports. Communication beyond the RRT members includes regional level fora, use of media (TV and radio), and leaflets, among others. The choice of what kind of stakeholders to involve depends on the task at hand, although high-level policymakers or representatives of development institutions are usually preferred.

Data Limitations

The data challenge is acute in SSA. Modeling efforts are often limited by single climate-station datasets or agronomic trials that represent wide geographic areas. For example, only one station's short-term weather dataset was available in Caprivi, Namibia. Even where multiple stations exist, e.g., in Bloem and Thabanchu in South Africa, there are often large data gaps. The problem is especially severe for IA where both crop and socio-economic datasets are needed; often good data are available for one but not the other domain.

Proper archiving of and access to primary datasets by the scientific community is a key recommendation, especially for SSA (Cooper *et al.*, 2013), and a key element in AgMIP. At the global level of AgMIP, there is a dedicated IT team that is developing infrastructure for data- and information-sharing for the research community and

Box 1. Climate change impacts on pests and diseases.

The inclusion of pest and diseases in modeling is entering AgMIP's mainstream research. Many crop modeling initiatives do not normally account for effects of pest and diseases, let alone focus on this in the context of climate change. The existing though scanty information indicates that as global warming progresses, latitudinal (and altitudinal) shifts of crop pests are expected, depending on the species (Bebber *et al.*, 2013). For example, the tomato red spider mite (*Tetranychus evansi*) is predicted to shift from the current tropical countries in South America and Africa, and temperate regions in North America, the Mediterranean basin and Australia towards northern Europe and some other temperate regions in the Americas by 2080 (Meynard *et al.*, 2013).

Africa and other tropical countries will also have to cope with species shifts of viruses and nematodes towards the equator (Bebber *et al.*, 2013). In South Africa, and as expected in other zones, differences in ecosystems within a region will have different rates of pests and pathogen development. Van der Waals *et al.* (2013) predicts the cumulative relative development rate (cRDR) of early blight and brown spot in South Africa to increase in the wet winter and wet summer crops of the Sandveld and Eastern Free State, respectively, but to remain unchanged in the dry summer and dry winter crops of the Sandveld and Limpopo, respectively. The cRDR of late blight in all of the cropping systems modeled in this study will decrease, except in the wet winter crop of the Sandveld. This and other approaches encompass uncertainties related to species prevalence, modeling method, and environmental response due to differences within species (as shown by Meynard *et al.*, 2013).

How will pest and disease populations affect productivity and economies of future households? This is one of the questions that AgMIP is aiming to answer by capturing climate change effects on pest and disease pressures within dynamic crop growth models.

stakeholders (see also Part 1, Chapter 6 in this volume). To guide usability, AgMIP has defined categories of experimental "sentinel site" field data as silver, gold, or platinum, based on how comprehensive the data is for use in model development, calibration, and validation (see Part 2, Chapter 13 in this volume). In SSA, most of the data are silver or lower categories. This realization is motivating scientists to design new experiments within other funded projects in SSA to ensure improved data collection consistent with modeling requirements. Stakeholders have indicated willingness to mobilize consistent data collection for integrated assessments, e.g., in Mozambique. Data archiving is, as expected, accompanied by metadata that includes information on data collection, quality control, and restrictions on usage.

Access to data required for IA has been a major challenge for the AgMIP RRTs. Extending partnerships to include institutions with needed data, paying for data acquisition, and collecting new data to fill in gaps on agronomic and field management practices were some of the ways to circumvent the data challenge. In some cases, it was not possible to match simulated yields directly with those observed from specific sites but rather comparison of yield distributions of both simulated and observed yields were carried out. Given the usefulness of this approach, there is the need for data collection in subsequent IAs to enable matched-case comparisons.

Multiple-model approaches require IT support and development of data-translation tools. AgMIP tools include R scripts, and visual basic macros (e.g., AgMIP's QuadUI) for data formatting, transformations, and analysis. For details of data translation and other AgMIP IT tools, see also Part 2, Chapter 6 in this volume and agmip.org.

Regional Contrasts

Research results for climate change across SSA are all consistent with a warmer future world, with temperature increases for all emission scenarios, GCMs, and locations (Table 3). Temperatures are projected to increase by 1.5 to 3.5°C in Southern Africa, 0.6 to 3.9°C in East Africa, and 1.7 to 3.2°C in West Africa, according to modeled locations and GCMs used in the AgMIP regional integrated assessments. Rainfall projections, however, are variable, with four of five GCMs showing a wetter East Africa, while West Africa is projected to have reduced rainfall for a majority of the GCMs, although again this varies by the specific subregion. The new results for West Africa show that the northwest will become drier, the northeast will become wetter, while the south will be unchanged (see Part 2, Chapter 2 in this volume).

Table 3. Expected changes in future regional rainfall and temperatures in specific locations in SSA as projected in AgMIP for the mid-century (2040–2069) with selected GCMs and RCP8.5.

	East Africa (AgMIP EA)		Southern Africa (SAAMIIP)		Southern Africa (CLIP)		West Africa (CIWARA)[β]	
	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.
CCSM4	+	+	−	+	−	+	−	+
GFDL-ESM2M	+	−	−	+	−	+	+	+
HadGEM2-ES	+	+	+	+	−	+	−	+
MIROC5	−	+	−	+	−	+	0	+
MPI-ESM-MR	+	+	−	+	−	+	−	+

+ = increase, − = decrease, 0 = no change, [β]for Nioro site, Senegal.

Besides the subregional variations that are expected as shown earlier, Hastenrath and Polzin (2011) reported variations of observed long-term rainfall in the West African Sahel as prolonged (>10 years) dry and wet regimes that could repeat and influence future climate change. In line with these, Eden *et al.* (2014) have emphasized the need for improved understanding of atmospheric and oceanic drivers of different precipitation regimes as a way of understanding African regional climate changes.

Adaptation options arising from AgMIP

Plausible adaptation options that have arisen from AgMIP scientist–stakeholder discussions include:

(1) The need to consider crop insurance.
(2) Addressing the threats and barriers preventing farmers from moving to the desired state, including soil degradation.
(3) Increases in resilience to pests and diseases.
(4) Low-input costs as well as quality and timely supply of inputs.
(5) Better market development and extension capacity.
(6) Addressing demands for energy that are driving deforestation in SSA.
(7) Enhancing sustainability by including organic resources in modeling scenarios.
(8) Switching to other crops or system diversification.
(9) Non-monetary advancement of sowing dates (appropriate targeting).
(10) Weather forecasting and real-time weather advisories.
(11) Increased use of groundwater for supplemental irrigation, water harvesting, and improving crop and systems water-use efficiency.
(12) Cultivars that optimize water demands at the various crop stages.
(13) Optimized planting density, cultivars tolerant to heat stress, genetically improved long- and short-duration varieties.
(14) Introduction of animal husbandry.

There should be different adaptation strategies for the different categories (operational scale, poverty level, etc.) of farmers, and the strategies should be linked to the livelihoods and show their clear gains. Stakeholder experiences and inputs are needed to help ensure the testing of most appropriate adaptation packages among many options.

Conclusions

AgMIP has a unique approach with good integration between the different disciplines and sectors. It allows for a more holistic approach in assessing climate change impacts and their effects on the income levels of households. AgMIP's need for

good data for integrated modeling within SSA is spurring the setting up of new experiments to generate more high-quality datasets. Further investment in research and development is needed to develop recommendations for the different production systems and environments, and to further capacity building at the national level. The stakeholder involvement process is but one step and in the next phase, AgMIP should engage more with stakeholders for this knowledge to reach the users. Current research is helping identify the most vulnerable farmers so that policymakers can make plans to help those categories, to minimize climate-related risks.

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